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Rundle

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(54) **EAR PRESENCE DETECTION IN NOISE CANCELLING EARPHONES**

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H04R 1/10 (2006.01)

(52) **U.S. Cl.**
CPC ***H04R 1/1083*** (2013.01); *H04R 2460/01* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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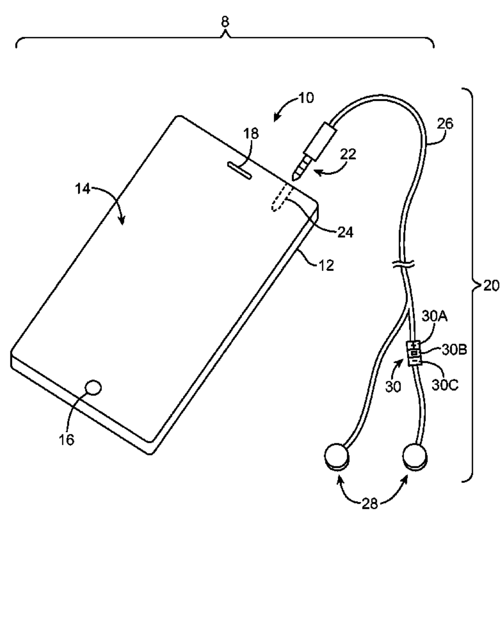
(57) **ABSTRACT**

An electronic device may be coupled to an accessory such as a pair of earphones. The earphones may have noise cancellation features that may be implemented using noise cancellation circuitry in the earphones or in the electronic device. The earphones may have ear presence sensor structures that determine whether speakers in the earphones are present at the ears of a user. In one suitable embodiment, control circuitry in the earphones may be used to adjust noise cancellation circuitry in the earphones based on information from the ear presence sensor structures. For example, the control circuitry may deactivate noise cancellation circuitry in response to receiving information from the ear presence sensor structures indicating that the earphones have been removed from a user's ears. In another suitable embodiment, control circuitry in the electronic device may adjust noise cancellation circuitry in the electronic device based on information from the ear presence sensor structures.

17 Claims, 7 Drawing Sheets



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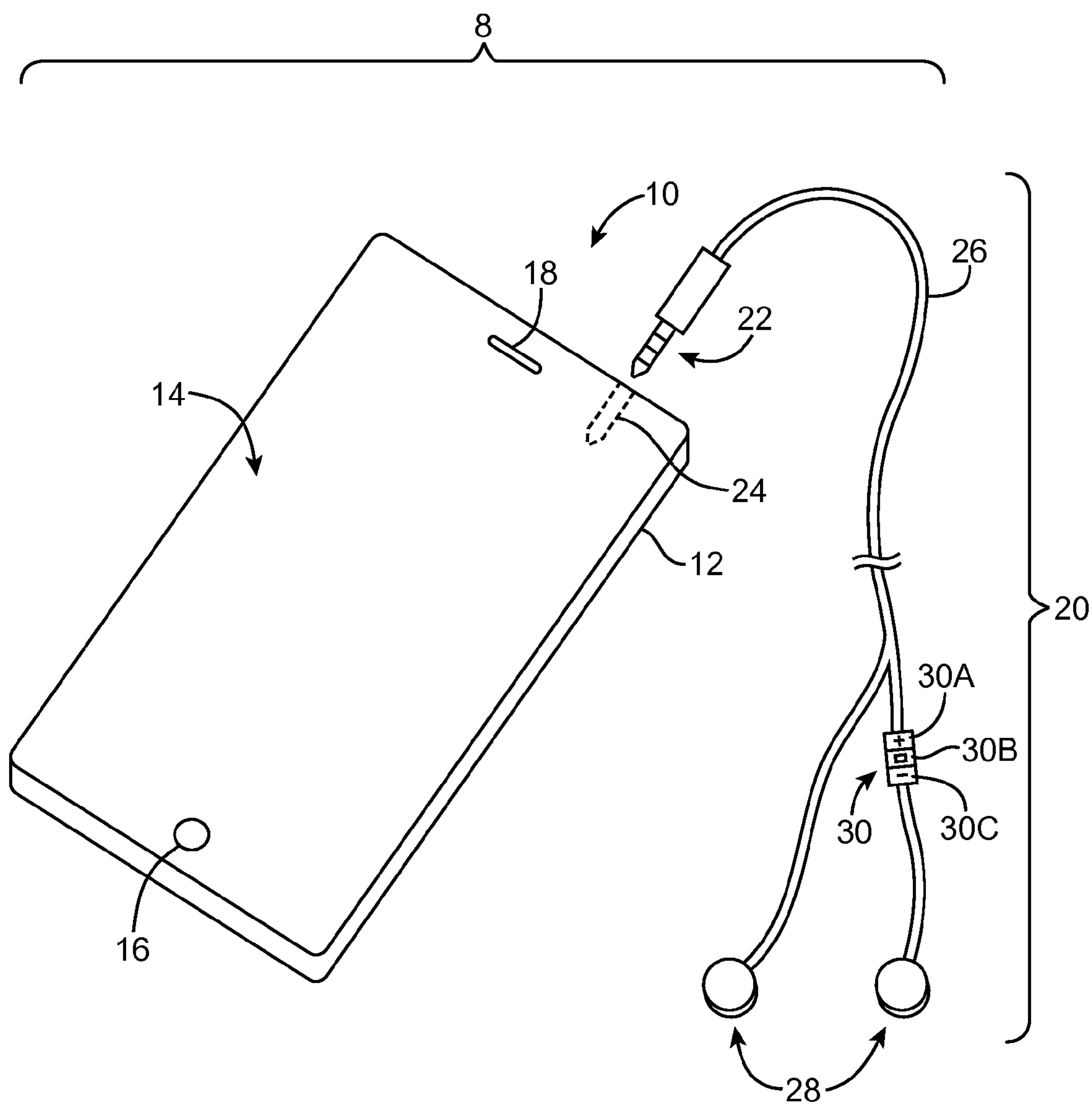

FIG. 1

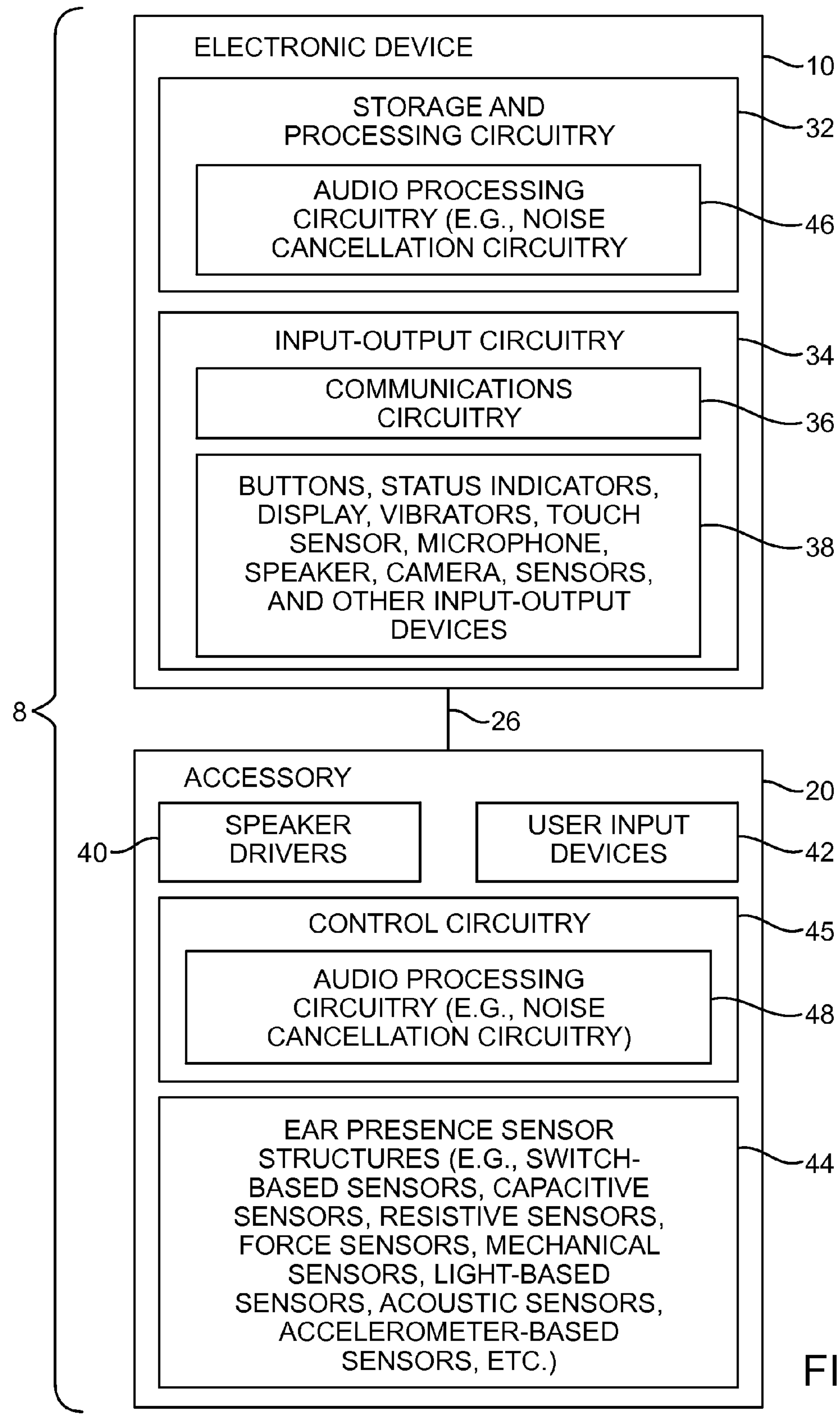
ELECTRONIC DEVICE
10
STORAGE AND PROCESSING CIRCUITRY
32
AUDIO PROCESSING CIRCUITRY (E.G., NOISE CANCELLATION CIRCUITRY
46
INPUT-OUTPUT CIRCUITRY
34
COMMUNICATIONS CIRCUITRY
36
BUTTONS, STATUS INDICATORS, DISPLAY, VIBRATORS, TOUCH SENSOR, MICROPHONE, SPEAKER, CAMERA, SENSORS, AND OTHER INPUT-OUTPUT DEVICES
38
8
26
ACCESSORY
20
40
SPEAKER DRIVERS
USER INPUT DEVICES
42
CONTROL CIRCUITRY
45
AUDIO PROCESSING CIRCUITRY (E.G., NOISE CANCELLATION CIRCUITRY)
48
EAR PRESENCE SENSOR STRUCTURES (E.G., SWITCH-BASED SENSORS, CAPACITIVE SENSORS, RESISTIVE SENSORS, FORCE SENSORS, MECHANICAL SENSORS, LIGHT-BASED SENSORS, ACOUSTIC SENSORS, ACCELEROMETER-BASED SENSORS, ETC.)
44

FIG. 2

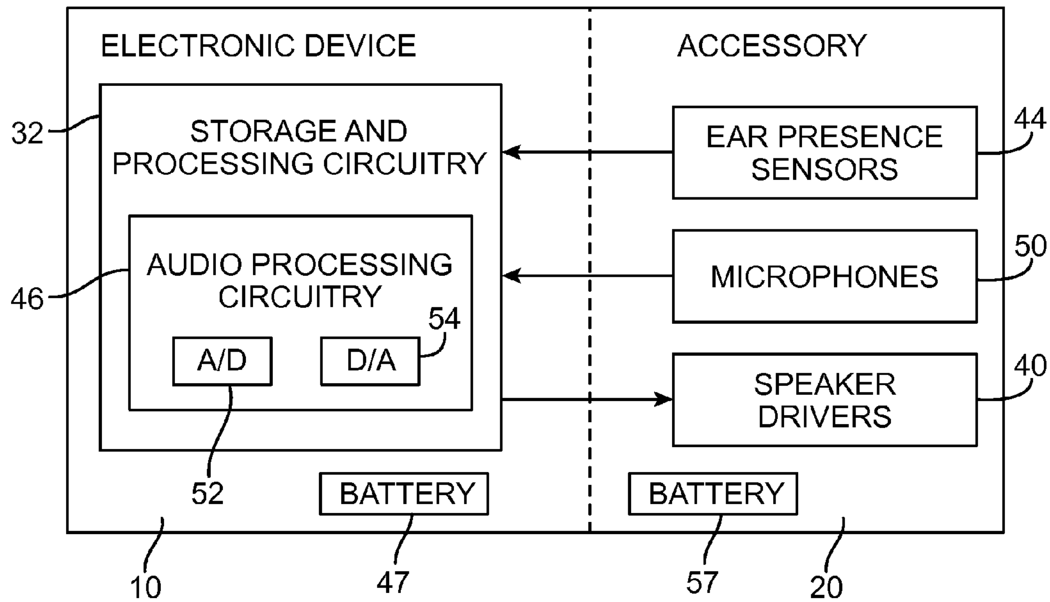
ELECTRONIC DEVICE
ACCESSORY
STORAGE AND PROCESSING CIRCUITRY
AUDIO PROCESSING CIRCUITRY
A/D
D/A
EAR PRESENCE SENSORS
MICROPHONES
SPEAKER DRIVERS
BATTERY
BATTERY
32
46
54
52
44
50
40
10
47
57
20

FIG. 3

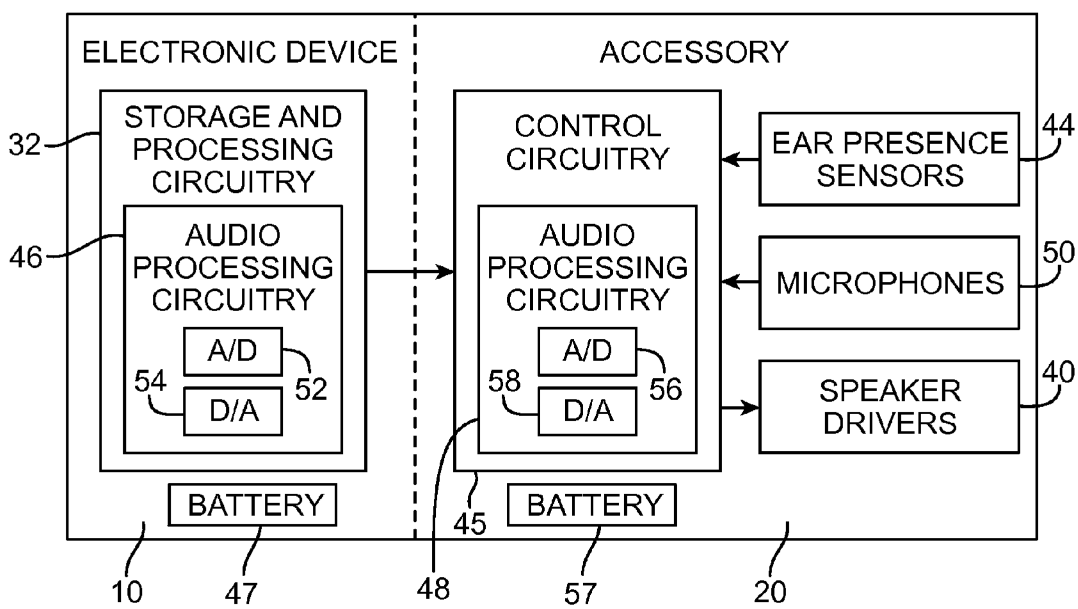
ELECTRONIC DEVICE
ACCESSORY
STORAGE AND PROCESSING CIRCUITRY
AUDIO PROCESSING CIRCUITRY
A/D
D/A
CONTROL CIRCUITRY
AUDIO PROCESSING CIRCUITRY
A/D
D/A
EAR PRESENCE SENSORS
MICROPHONES
SPEAKER DRIVERS
BATTERY
BATTERY
32
46
54
52
58
56
44
50
40
45
10
47
48
57
20

FIG. 4

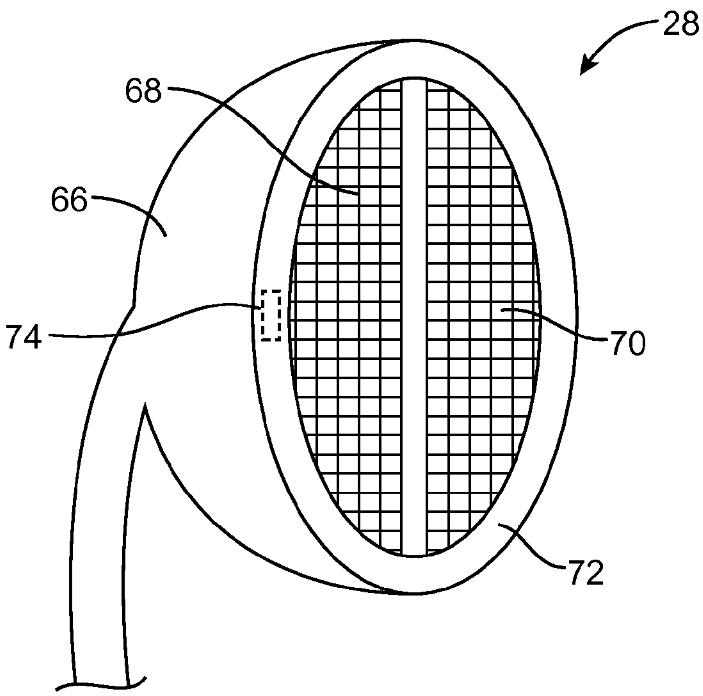

FIG. 5

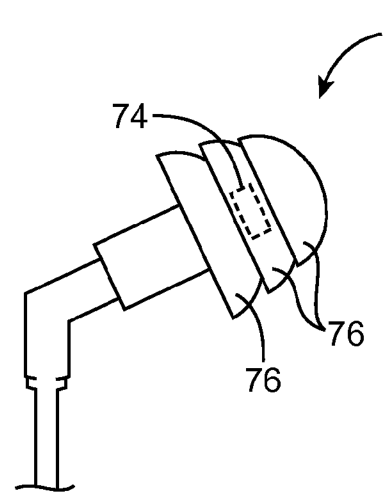

FIG. 6

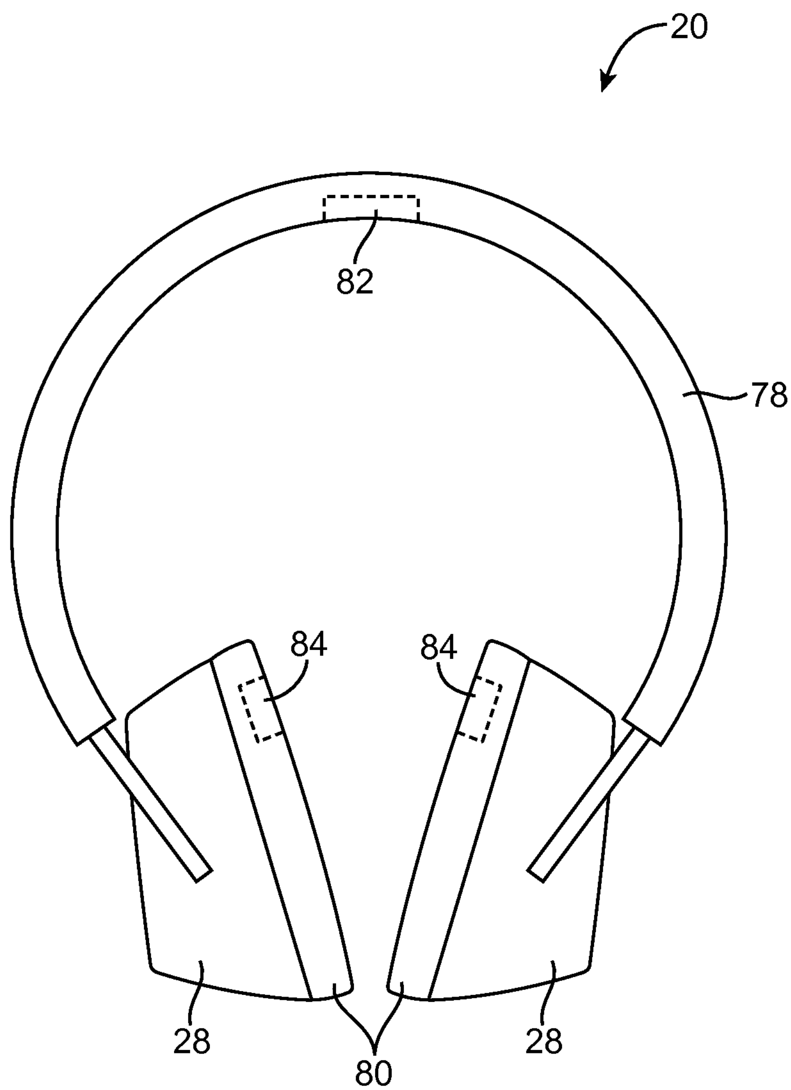

FIG. 7

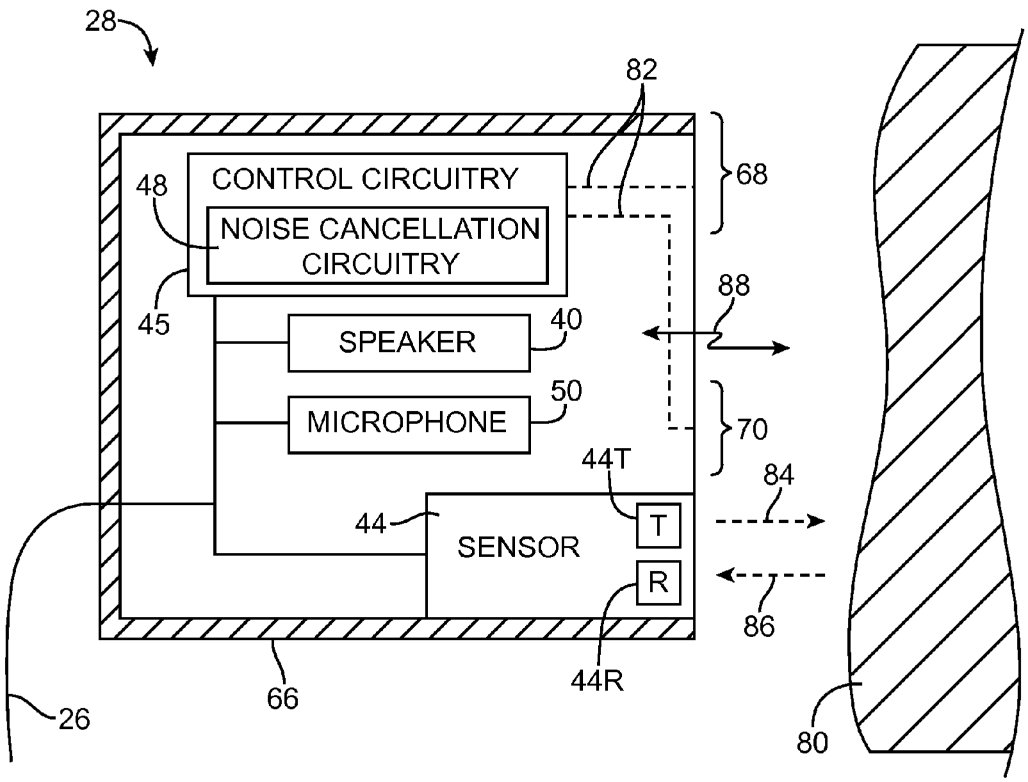
28
82
68
CONTROL CIRCUITRY
48
NOISE CANCELLATION CIRCUITRY
45
88
SPEAKER
40
50
MICROPHONE
70
44T
84
44
T
SENSOR
R
86
44R
66
26
80

FIG. 8

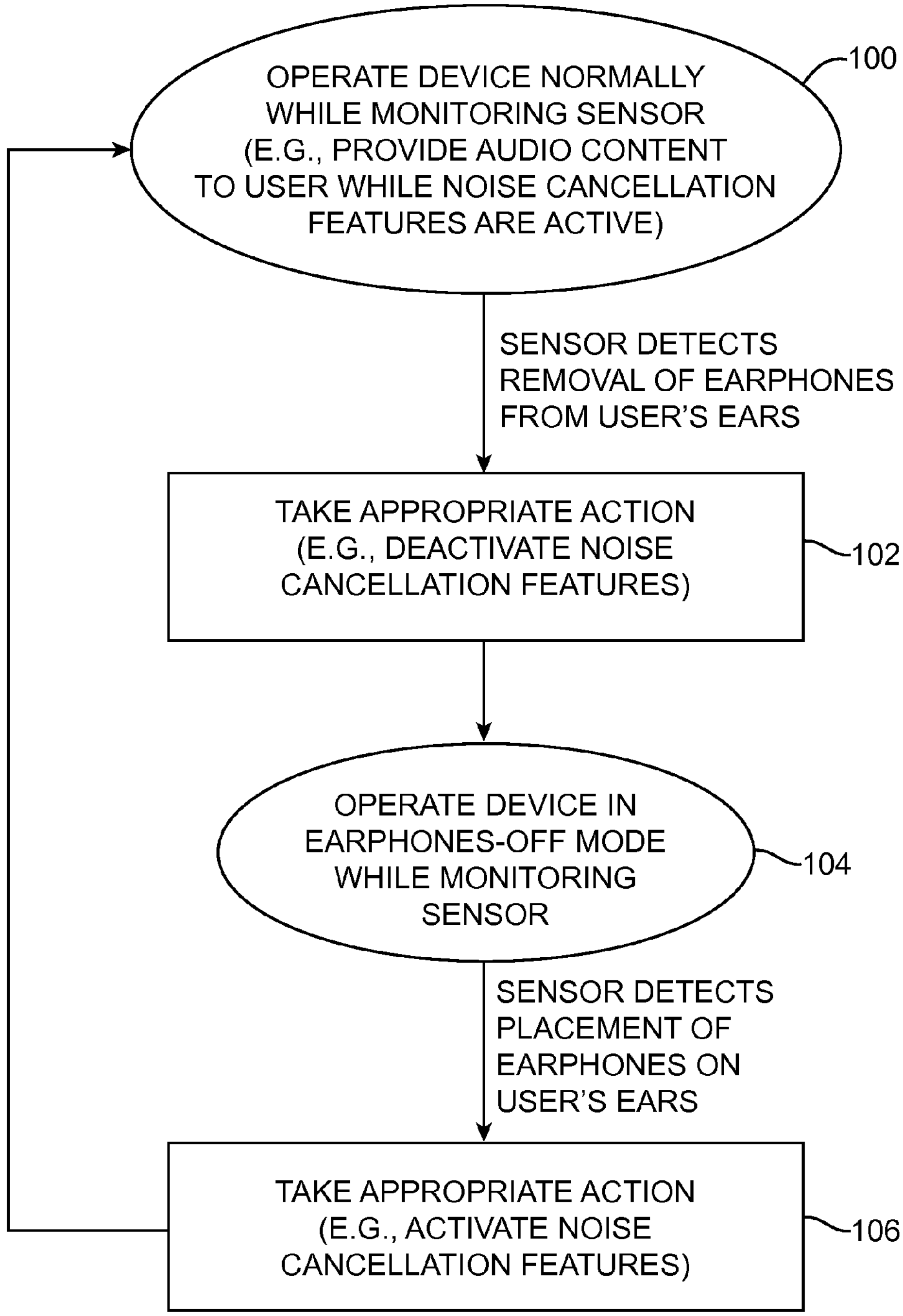
OPERATE DEVICE NORMALLY WHILE MONITORING SENSOR (E.G., PROVIDE AUDIO CONTENT TO USER WHILE NOISE CANCELLATION FEATURES ARE ACTIVE)
100
SENSOR DETECTS REMOVAL OF EARPHONES FROM USER'S EARS
TAKE APPROPRIATE ACTION (E.G., DEACTIVATE NOISE CANCELLATION FEATURES)
102
OPERATE DEVICE IN EARPHONES-OFF MODE WHILE MONITORING SENSOR
104
SENSOR DETECTS PLACEMENT OF EARPHONES ON USER'S EARS
TAKE APPROPRIATE ACTION (E.G., ACTIVATE NOISE CANCELLATION FEATURES)
106

FIG. 9

EAR PRESENCE DETECTION IN NOISE CANCELLING EARPHONES

BACKGROUND

This relates to electronic devices and, more particularly, to electronic devices with accessories such as earphones.

Accessories such as earphones are often used with media players, cellular telephones, and other electronic devices. Some accessories have microphones that are used to form part of a noise cancellation circuit. When noise cancellation functions are active, the impact of ambient noise on audio playback can be reduced. Microphones can also be used to implement voice microphone noise cancellation.

There can be difficulties associated with noise cancelling earphones. For example, a user who is using earphones to listen to audio while noise cancellation circuitry in the earphones is active may occasionally need to remove the earphones. When doing so, the user may not be able to manually turn off noise cancellation features. Actively running noise cancellation operations in an accessory when a user is not using the accessory increases power consumption and decreases the battery life of the accessory.

It would therefore be desirable to be able to provide improved ways in which to control operation of an electronic device coupled to an accessory such as noise cancelling earphones.

SUMMARY

An electronic device may be coupled to an accessory such as a pair of earphones having noise cancellation features. The noise cancellation features may be used to reduce the impact of ambient noise on the audio content that is played through the earphones.

The earphones may have ear presence sensor structures that determine whether or not speakers in the earphones are present at the ears of the user. Information from the ear presence sensor structures may be used to control the operation of the noise cancellation features. In one suitable embodiment, noise cancellation features may be implemented using noise cancellation circuitry in the earphones. With this type of configuration, control circuitry in the earphones may adjust the noise cancellation circuitry in response to information from the ear presence sensor structures. For example, control circuitry in the earphones may automatically deactivate noise cancellation circuitry when information from the ear presence sensor structures indicates that the earphones have been removed from a user's ears. When information from the ear presence sensor structures indicates that the earphones have been placed in or on the user's ears, the control circuitry in the earphones may, if desired, automatically activate the noise cancellation circuitry.

In another suitable embodiment, noise cancellation features may be implemented using noise cancellation circuitry in the electronic device. With this type of configuration, information from ear presence sensor structures may be conveyed to control circuitry in the electronic device. The control circuitry may adjust the noise cancellation circuitry in response to information received from the ear presence sensor structures. For example, control circuitry in the electronic device may automatically deactivate noise cancellation circuitry when information from the ear presence sensor structures indicates that the earphones have been removed from a user's ears. When information from the ear presence sensor structures indicates that the earphones have been placed in or on the user's ears, the control circuitry in the earphones may, if desired, automatically activate the noise cancellation circuitry.

Controlling the operation of noise cancellation circuitry based on whether or not the earphones are present at the user's ears may reduce the power consumption of a battery in the earphones or in the electronic device.

The ear presence sensor structures may include switch-based sensors, accelerometer-based sensors, light-based sensors, or other suitable types of sensors.

Further features of the invention, its nature and various advantages will be more apparent from the accompanying drawings and the following detailed description of the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a front perspective view of an illustrative electronic device and associated accessory in accordance with an embodiment of the present invention.

FIG. **2** is a schematic diagram of an illustrative electronic device and associated accessory in accordance with an embodiment of the present invention.

FIG. **3** is a schematic diagram of an illustrative electronic device and associated accessory in which noise cancellation circuitry is located in the electronic device in accordance with an embodiment of the present invention.

FIG. **4** is a schematic diagram of an illustrative electronic device and associated accessory in which noise cancellation circuitry is located in the accessory in accordance with an embodiment of the present invention.

FIG. **5** is a perspective view of an illustrative speaker housing such as an earbud speaker housing that has ear presence sensor structures in accordance with an embodiment of the present invention.

FIG. **6** is a perspective view of an illustrative speaker housing such as an in-ear speaker housing that has ear presence sensor structures in accordance with an embodiment of the present invention.

FIG. **7** is a perspective view of illustrative earphones such as over-the-ear headphones that have ear presence sensor structures in accordance with an embodiment of the present invention.

FIG. **8** is a cross-sectional side view of an earphone housing of the type that may be provided with sensor structures for detecting the presence of an ear or other external object in accordance with an embodiment of the present invention.

FIG. **9** is a flow chart of illustrative steps involved in using an electronic device and accessory having noise cancellation features in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

Electronic device accessories such as earphones may be provided with noise cancellation features. When noise cancellation features are activated, the impact of ambient noise on audio content that is played through the earphones can be reduced. Noise cancellation features may also be used to perform voice microphone noise cancellation.

Noise cancellation features may be implemented using one or more noise cancellation microphones. For example, a voice microphone in the accessory may have an associated noise cancellation microphone that picks up ambient noise in the vicinity of the voice microphone.

Earphone speaker housings in an accessory may also have noise cancellation microphones. For example, each earphone speaker housing in a headset may have an external noise cancellation microphone on an outer surface of the earphone speaker housing. In addition to the external noise cancellation microphone or instead of the external noise cancellation microphone, each earphone speaker housing may have an internal noise cancellation microphone on an interior surface of the earphone speaker housing (e.g., adjacent to the ear).

In accessories with more speakers, more noise cancellation microphones may be used. For example, additional noise cancellation microphones can be provided in earbuds that contain multiple drivers or in surround sound accessories. A surround sound accessory might, for example, have five or six speakers (or more) and might have a noise cancellation microphone that is adjacent to each respective speaker.

Accessories such as earphones having noise cancellation features may be provided with the ability to sense the presence of external objects. For example, an earphone accessory may be provided with sensor structures such as ear presence sensor structures that can determine whether or not the earphones (i.e., the earphone speakers) are located in or on the ears of a user.

Information gathered by the sensor structures may be used to control the operation of noise cancellation features in the earphones. For example, control circuitry in the accessory or in the electronic device may automatically activate or deactivate noise cancellation features based on whether or not the earphones are located in or on the ears of a user. Controlling noise cancellation features in a pair of earphones coupled to an electronic device based on whether or not the user is wearing the earphones may reduce power consumption and extend the battery life of the earphones and/or of the electronic device.

FIG. **1** is a diagram of a system of the type that may be provided with an accessory having noise cancellation features for reducing the impact of ambient noise and sensing structures for detecting the presence of external objects such as the ears of a user. As shown in FIG. **1**, system **8** may include electronic device **10** and accessory **20**.

Electronic device **10** may include a display such as display **14**. Display **14** may be a touch screen that incorporates a layer of conductive capacitive touch sensor electrodes or other touch sensor components or may be a display that is not touch-sensitive. Display **14** may include an array of display pixels formed from liquid crystal display (LCD) components, an array of electrophoretic display pixels, an array of plasma display pixels, an array of organic light-emitting diode display pixels, an array of electrowetting display pixels, or display pixels based on other display technologies. Configurations in which display **14** includes display layers that form liquid crystal display (LCD) pixels may sometimes be described herein as an example. This is, however, merely illustrative. Display **14** may include display pixels formed using any suitable type of display technology.

Display **14** may be protected using a display cover layer such as a layer of transparent glass or clear plastic. Openings may be formed in the display cover layer. For example, an opening may be formed in the display cover layer to accommodate a button such as button **16** and an opening such as opening **18** may be used to form a speaker port.

Device **10** may have a housing such as housing **12**. Housing **12**, which may sometimes be referred to as an enclosure or case, may be formed of plastic, glass, ceramics, fiber composites, metal (e.g., stainless steel, aluminum, etc.), other suitable materials, or a combination of any two or more of these materials.

Housing **12** may be formed using a unibody configuration in which some or all of housing **12** is machined or molded as a single structure or may be formed using multiple structures (e.g., an internal frame structure, one or more structures that form exterior housing surfaces, etc.). The periphery of housing **12** may, if desired, include walls. One or more openings may be formed in housing **12** to accommodate connector ports, buttons, and other components. For example, an opening may be formed in the wall of housing **12** to accommodate audio connector **24** and other connectors (e.g., digital data port connectors, etc.). Audio connector **24** may be a female audio connector (sometimes referred to as an audio jack) that has two pins (contacts), three pins, four pins, or more than four pins (as examples). Audio connector **24** may mate with male audio connector **22** (sometimes referred to as an audio plug) in accessory **20**.

Accessory **20** may be a pair of earphones (e.g., earbuds or earphones with other types of speakers), other audio equipment (e.g., an audio device with a single earbud unit), or other electronic equipment that communicates with electronic device **10**. The use of a pair of earphones in system **8** is sometimes described herein as an example. This is, however, merely illustrative. Accessory **10** may be implemented using any suitable electronic equipment.

It should be understood that the term "earphones" may refer to any suitable type of audio headset (e.g., headphones, over-the-ear headphones, earbuds, earbud-type headphones with ear hooks, in-ear headphones that extend partially into the ear canal, etc.).

As shown in FIG. **1**, accessory **20** may include a communications path such as cable **26** that is coupled to audio plug **22**. Cable **26** may contain conductive lines (e.g., wires) that are coupled to respective contacts (pins) in audio connector **22**. The conductive lines of cable **26** may be used to route audio signals from device **10** to speakers in earphone units **28**. Earphone units **28** (which may sometimes be referred to as speakers or earphone housings) may include sensor structures for determining when earphone units **28** have been placed within the ears of a user. Microphone signals may be gathered using a microphone mounted in controller unit **30**. Controller unit **30** may also have buttons that receive user input from a user of system **8**. A user may, for example, manually control the playback of media by pressing button **30**A to play media or increase audio volume, by pressing button **30**B to pause or stop media playback, and by pressing button **30**C to reverse media playback or decrease audio volume (as examples).

The circuitry of controller **30** may communicate with the circuitry of device **10** using the wires or other conductive paths in cable **26** (e.g., using digital and/or analog communications signals). The paths in cable **26** may also be coupled to speaker drivers in earphones **28**, so that audio signals from device **10** may be played through the speakers in earbuds **28**. Electronic device **10** may regulate the volume of sound produced by earbuds **28** by controlling the audio signal strength used in driving the speakers in earbuds **28**.

In one suitable embodiment, sensor signals from sensor structures in earbuds **28** may be conveyed to device **10** using the conductive paths of cable **26**. With this type of configuration, electronic device **10** may process the sensor signals and take suitable action based on a determination of whether or not earphones **20** are located in or on a user's ears.

A schematic diagram showing illustrative components that may be used in device **10** and accessory **20** of system **8** is shown in FIG. **2**. As shown in FIG. **2**, electronic device **10** may include control circuitry **32** and input-output circuitry **34**. Control circuitry **32** may include storage and processing circuitry that is configured to execute software that controls the operation of device **10**. Control circuitry **32** may be implemented using one or more integrated circuits such as microprocessors, application specific integrated circuits, memory, and other storage and processing circuitry. Control circuitry **32** may, if desired, include noise cancellation circuitry and other audio processing circuitry **46**.

Input-output circuitry **34** may include components for receiving input from external equipment and for supplying output. For example, input-output circuitry **34** may include user interface components for providing a user of device **10** with output and for gathering input from a user. As shown in FIG. **2**, input-output circuitry **34** may include communications circuitry **36**. Communications circuitry **36** may include wireless circuitry such as radio-frequency transceiver circuitry with a radio-frequency receiver and/or a radio-frequency transmitter. Radio-frequency transceiver circuitry in the wireless circuitry may be used to handle wireless signals in communications bands such as the 2.4 GHz and 5 GHz WiFi® bands, cellular telephone bands, and other wireless communications frequencies of interest. Communications circuitry **36** may also include wired communications circuitry such as circuitry for communicating with external equipment over serial and/or parallel digital data paths.

Input-output devices **38** may include buttons such as sliding switches, push buttons, menu buttons, buttons based on dome switches, keys on a keypad or keyboard, or other switch-based structures. Input-output devices **38** may also include status indicator lights, vibrators, display touch sensors, speakers, microphones, camera sensors, ambient light sensors, proximity sensors, and other input-output structures.

Electronic device **10** may be coupled to components in accessory **20** using cables such as cable **26** of accessory **20**. Accessory **20** may include speakers such as a pair of speaker drivers **40** (e.g., a left speaker and a right speaker). If desired, accessory **20** may include more than one driver per earbud. For example, each earbud in accessory **20** may have a tweeter, a midrange driver, and a bass driver (as an example). Speaker drivers **40** may be mounted in earbuds or other earphone housings. The use of left and right earbuds to house respective left and right speaker drivers **40** is sometimes described herein as an example.

Accessory **20** may include control circuitry such as control circuitry **45**. Control circuitry **45** may, for example, include storage and processing circuits formed from one or more integrated circuits or other circuitry. Circuitry **45** in accessory **20** may include noise cancellation circuitry and other audio processing circuitry **48**, if desired.

Cables such as cable **26** may form a communications path that can be used in conveying signals between device **10** and accessory **20**. The communications path may be used to transmit audio from circuitry **32** to speaker drivers **40** during playback operations.

The communications path may also be used to convey noise signals. Noise cancellation may, for example, be performed using the processing circuitry of device **10** (e.g., using noise cancellation circuitry **46**). In this type of arrangement, noise signals gathered by one or more microphones in earphones **20** may be routed to circuitry **46**. Circuitry **46** may then route audio signals from which noise has been cancelled to headset **20**. If desired, noise cancellation operations may be performed locally in headset **20**. With this type of arrangement, noise cancellation circuitry **48** in headset **20** can receive audio playback signals from device **10** and can receive noise signals from noise cancellation microphones in earphones **20**. Circuitry **48** can then cancel noise from the played back audio.

If desired, accessory **20** may include user input devices **42** such as buttons (see, e.g., the buttons associated with button controller **30** of FIG. **1**), touch-based input devices (e.g., touch screens, touch pads, touch buttons), a microphone to gather voice input, other microphones such as noise cancellation microphones, and other user input devices.

To determine whether or not the earbuds in which speaker drivers **40** are located in or on the ears of a user, accessory **20** may be provided with ear presence sensor structures **44**. Ear presence sensor structures **44** may be configured to detect whether or not the speakers of earphones **20** are present at the ears of a user. Ear presence sensors may be formed from force sensors, from switches or other mechanical sensors, from capacitive sensors, from resistance-based sensors, from light-based sensors, from accelerometer-based sensors, and from acoustic-based sensors such as ultrasonic acoustic-based sensors (as examples). Control circuitry **45** in accessory **20** and/or control circuitry **32** of electronic device **10** may use information from ear presence sensor structures **44** in determining which actions should be automatically taken by device **10** and/or by accessory **20**.

A schematic diagram of device **10** and accessory **20** in a configuration in which noise cancellation circuitry is located in device **10** is shown in FIG. **3**. As shown in FIG. **3**, accessory **20** may include one or more microphones such as microphones **50**. Microphones **50** may include noise cancellation microphones that are used to gather ambient noise signals associated with speakers **40**. For example, a first microphone **50** may be configured to gather ambient noise signals associated with a left speaker driver **40**, while a second microphone **50** may be configured to gather ambient noise signals associated with a right speaker driver **40**. Using noise cancellation techniques, the ambient noise signals can be used to reduce noise in the audio being played through speakers **40**.

Noise cancellation techniques can also be implemented for microphones. For example, microphones **50** may include a voice microphone and a corresponding noise cancellation microphone. The voice microphone may be used to gather a user's voice signals during telephone calls or to record audio clips, while the corresponding noise cancellation microphone may be used to gather ambient noise signals associated with the voice microphone. Ambient noise signals gathered by the noise cancellation microphone may be used to reduce noise in the voice signals gathered by the voice microphone.

Noise cancellation operations may be performed using analog circuitry or using digital processing techniques. Noise cancellation operations may be performed locally in accessory **20** or may be performed remotely in device **10**. In the example of FIG. **3**, noise cancellation operations are performed remotely in device **10**.

As shown in FIG. **3**, device **10** may include audio processing circuitry **46**. Audio processing circuitry **46**, which is sometimes referred to as a codec or audio codec, may be used to generate audio signals, to receive and process audio signals, and to receive and process sensor signals from sensor structures **44**. Circuitry **46** may include analog-to-digital (A/D) converter circuitry **52** and digital-to-analog (D/A) converter circuitry **54**. Analog-to-digital converter circuitry **52** in device **10** may be used to digitize analog signals such as analog audio signals. For example, analog-to-digital converter circuitry **52** may be used to digitize one or more analog microphone signals such as analog microphone signals gathered by microphones **50**. Digital-to-analog converter circuitry **54** may be used to generate analog output signals. For example, digital-to-analog converter circuitry **54** may receive digital signals corresponding to the audio portion of a media playback event, audio for a telephone call, noise signals, an alert tone or signal (e.g., a beep or ring), or any other digital information. Based on this digital information, digital-to-analog converter circuitry **54** may produce corresponding analog signals (e.g., analog audio).

Audio processing circuitry **46** may be powered by a power source such as battery **47**. If desired, accessory **20** may also include a power source such as battery **57**. This is, however, merely illustrative. The use of a battery such as battery **57** in accessory **20** is optional and is only shown as an illustrative example.

Audio processing circuitry **46** may include a digital signal processor that may be used to perform digital signal processing on digitized audio signals. For example, if operating accessory **20** in a noise cancellation mode, noise signals from microphones **50**, which may reflect the amount of ambient noise in the vicinity of speaker drivers **40** and/or the amount of ambient noise in the vicinity of a voice microphone) may be conveyed to audio processing circuitry **46** in device **10**. Using the processing capabilities of an audio digital signal processor in circuitry **46**, the noise signals can be digitally removed from digital audio voice signals and from digital speakers signals.

This is, however, merely illustrative. If desired, circuitry **46** may perform noise cancellation operations using analog noise cancellation circuitry. With this type of configuration, noise signals gathered by microphones **50** may be conveyed to circuitry **46** in device **10**. Audio processing circuitry **46** may produce an anti-noise signal and may convey the anti-noise signal to speaker drivers **40** along with the audio signal that is to be heard by the user. The anti-noise signal may be identical to the noise signal except that it is shifted by 180 degrees with respect to the noise signal. The anti-noise signal may be superimposed onto the noise signal such that destructive interference occurs and the two signals mutually cancel.

Noise cancellation circuitry of the type shown in FIG. **3** may be controlled manually by the user and/or may be controlled automatically based on sensor signals gathered by ear presence sensor structures **44**. For example, audio control circuitry **32** may automatically deactivate noise cancellation functions when information from sensor structures **44** indicates that earphones **20** have been removed from a user's ears and may automatically activate noise cancellation functions when information from sensor structures **44** indicates that earphones **20** have been placed in or on a user's ears. Because power is required to perform active noise cancellation operations, automatically controlling noise cancellation functions based on whether or not earphones **20** are in a user's ears may optimize the battery life of device **10**.

If desired, audio signal processing operations for implementing noise cancellation functions may be performed locally in accessory **20**. As shown in FIG. **4**, accessory **20** may include audio signal processing circuitry **48**. Circuitry **48** may include analog-to-digital converter circuitry **56** (e.g., for digitizing analog audio signals from a microphone in accessory **20**) and digital-to-analog converter circuitry **58** (e.g., to convert digital signals to analog signals that are played back through the speakers of accessory **20**). If desired, audio processing circuitry **48** may receive power from a power supply such as battery **57** or may be powered using other methods (e.g., device **10** may provide power to accessory **20** via cable **26** of FIG. **1**). The use of a battery such as battery **57** in accessory **20** is merely illustrative.

Circuitry **48** may be used to locally implement noise cancellation functions. In a typical local noise cancellation arrangement using digital processing techniques, analog microphone signals (noise signals) from microphones **50** are digitized using analog-to-digital circuitry **56**. Processing circuitry **48** may receive audio signals (e.g., played back music) from device **10** in digital form. Audio processing circuitry **48** may then use digital processing techniques to remove noise from the played back audio. The resulting audio signal may be converted to analog for speakers **40** using digital-to-analog converter circuitry **58**.

This is, however, merely illustrative. If desired, circuitry **48** may perform noise cancellation operations using analog noise cancellation circuitry. With this type of configuration, noise signals gathered by microphones **50** may be conveyed to circuitry **48** in accessory **20**. Audio processing circuitry **48** may produce an anti-noise signal and may convey the anti-noise signal to speaker drivers **40**. The anti-noise signal may be identical to the noise signal except that it is shifted by 180 degrees with respect to the noise signal. The anti-noise signal may be superimposed onto the noise signal such that destructive interference occurs and the two signals mutually cancel.

Noise cancellation circuitry of the type shown in FIG. **4** may be controlled manually by the user and/or may be controlled automatically based on sensor signals gathered by ear presence sensor structures **44**. For example, control circuitry **45** may automatically deactivate noise cancellation functions when information from sensor structures **44** indicates that earphones **20** have been removed from a user's ears and may automatically activate noise cancellation functions when information from sensor structures **44** indicates that earphones **20** have been placed in or on a user's ears. Because power is required to perform active noise cancellation operations, automatically controlling noise cancellation functions based on whether or not earphones **20** are in a user's ears may optimize the battery life of earphones **20**.

An illustrative earbud speaker housing with an ear presence sensor is shown in FIG. **5**. In the example of FIG. **5**, earbud **28** has a housing such as housing **66** in which one or more speaker drivers such as speakers **40** of FIG. **2** are mounted.

Conductive structures such as conductive mesh structures **68** and **70** may be mounted in housing **66**. As shown in FIG. **5**, for example, mesh structures **68** and **70** may be mounted in the front of housing **66** so that sound from the speakers inside earbud housing **66** may pass through the holes of the mesh. If desired, earbud **28** may contain microphone structures (e.g., when implementing noise cancellation features in earbud **28**). The use of mesh when forming electrode structures **68** and **70** may allow ambient sound to be picked up by the noise cancellation microphones in housing **66**.

Mesh electrodes **68** and **70** (e.g., metal screen structures) or other conductive structures in earbud **28** may be used as first and second terminals in a resistive (resistance-based) sensor. Control circuitry in housing **66** may be used to apply a voltage across the first and second terminals while measuring how much current flows as a result. The control circuitry may use information on the voltage and current signals that are established between electrodes **68** and **70** to determine whether or not earbud **28** has been placed in the ear of a user. In the absence of the user's ear, the resistance between electrodes **68** and **70** will be relatively high. When, however, earbud **28** has been placed into a user's ear, contact between electrodes **68** and **70** and the flesh of the ear will give rise to a lower resistance path between electrodes **68** and **70**.

To determine whether or not earbud **28** has been placed within the user's ear, control circuitry **45** of earbud (and/or control circuitry **32** of FIG. **2**) may measure the resistance between electrodes **68** and **70** and may compare the measured resistance to a predetermined threshold. When the measured resistance is below the predetermined threshold, circuitry **45** can conclude that earbud **28** has been placed in the ear of the user and may, if desired, automatically activate noise cancellation circuitry. When the measured resistance exceeds the predetermined threshold, circuitry **45** can conclude that earbud **28** is out of the ear and may, if desired, automatically deactivate noise cancellation circuitry.

In configurations where noise cancellation functions are performed remotely in device **10**, control circuitry **32** in device **10** may analyze sensor signals from ear presence sensors in earphones **20** and may automatically activate and deactivate noise cancellation circuitry in device **10** based on the sensor signals. Configurations in which noise cancellation is performed and controlled locally in earphones **20** and in which sensor signals from ear presence sensors are analyzed by control circuitry **45** in earphones **20** are sometimes described herein as an example.

In addition to or instead of using mesh **68** and **70** to measure the resistance of the user's ear, mesh electrodes **68** and **70** may be used as capacitive sensor electrodes (e.g., to make mutual capacitance measurements or to make self capacitance measurements). Different capacitance values may be detected in the presence and absence of the user's ear in the vicinity of electrodes **68** and **70**. This allows circuitry **45** to use the capacitance measurements to determine whether or not earbud **28** is in, on, or out of the user's ear.

If desired, earbud **28** may include a sealing member such as compressible sealing member **72**. Sealing member **72** may be used to form a seal between a user's ear and earbud **28** that helps block ambient noise while also forming an enclosed cavity adjacent to the ear canal. In addition to or instead of using mesh **68** and **70** to detect the presence of a user's ear, an ear presence sensor such as ear presence sensor **74** may be embedded in or formed on sealing member **72**.

As an example, ear presence sensor **74** may be a switch-based sensor such as a switch or button that is actuated when a user's ear is present or absent. Switch **74** may be mounted on an exterior surface of earbud housing **66** or may be embedded or formed on sealing member **72**. Switch **74** may be configured to move inwards (e.g., towards the interior of housing **66**) and to move outwards (e.g., towards the exterior of housing **66**). When earbud **28** is inserted into a user's ear, switch **74** may be compressed inward. When earbud **28** is out of the user's ear, switch **74** may move outwards to regain its original uncompressed state. Circuitry **45** may use information from switch structures such as switch structure **74** to determine whether or not earbud **28** has been placed in a user's ear. If desired, a switch-based ear presence sensor of this type may be implemented without requiring electrical power.

As additional examples, sensor structure **74** may be an accelerometer-based sensor, an orientation sensor, or other sensor that may be used in gathering earphone movement information and/or determining the location or orientation of earbud **28**. Changes in orientation and/or changes in acceleration may be used to determine whether or not earphones **20** are in or on a user's ears. For example, when movement is detected by sensor **74**, circuitry **45** can conclude that earphones **20** are not in the user's ears. When movement is not detected by sensor **74** for a predetermined period of time, circuitry **45** can conclude that earphones **20** are not in the user's ears.

If desired, ear presence sensor **74** may be a pressure or force sensor configured to measure a pressure or force against sealing member **72**. In force-based sensor schemes, the resistance of a compressible foam may be measured or a strain gauge output can be monitored. When force is present, circuitry **45** can conclude that earphones **20** have been inserted into or mounted on a user's ears, whereas when force is not present, circuitry **45** can conclude that earphones **20** are not being worn by the user. Force indicative of a user's ear pressing against earphones **20** may also be monitored using piezoelectric force sensors or other force sensors.

These examples are, however, merely illustrative. In general, any suitable type of sensor may be used to detect the presence and/or absence of a user's ear in the vicinity of earbud **28**.

FIG. **6** is a perspective view of an illustrative in-ear speaker housing with an ear presence sensor. In the example of FIG. **6**, in-ear earbud **28** includes sealing members **76** configured to extend partially into the ear canal of a user's ear. Earphones of the type shown in FIG. **6** are sometimes referred to as ear-canal headphones.

As shown in FIG. **6**, ear presence sensor **74** may be embedded in or formed on one of sealing members **76**. Ear presence sensor **74** may be an accelerometer-based sensor, a pressure or force sensor, a capacitive sensor, a switch-based sensor (e.g., sensor **74** may be a mechanical switch that is actuated when earbud **28** is inserted or removed from a user's ear), or any other suitable type of sensor configured to detect the presence and/or absence of a user's ear in the vicinity of earbud **28**.

FIG. **7** is a perspective view of illustrative over-the-ear headphones having one or more ear presence sensor structures. In the example of FIG. **7**, accessory **20** includes a headband such as headband **78** with left and right over-the-ear speaker housings **28**. A sealing member such as sealing member **80** may be a ring or layer of foam or may be any other suitable type of ear pad configured to form a seal around the user's ear to help block out ambient noise.

As shown in FIG. **7**, accessory **20** may include one or more user detection sensors such as ear presence sensor structures **82** and **84**. Ear presence sensor structures **84** may be embedded in or formed on sealing members **80** and may be configured to detect the presence and absence of a user's ears in the vicinity of speaker housings **28**. Ear presence sensor **82** may be embedded in or formed on headband portion **78** and may be configured to detect the presence and absence of a user's head adjacent to headband **78**. When information from sensor **82** indicates that a user's head is not present, device **10** can conclude that the user is not wearing headphones **20**. When information from sensor **82** indicates that a user's head is present, device **10** can conclude that the user is wearing headphones **20**.

Ear presence sensor structures **82** and **84** may be accelerometer-based sensors, pressure or force sensors, capacitive sensors, acoustic-based sensors, switch-based sensors (e.g., sensors formed form mechanical switches that are actuated when a user's ear or head is present or absent), or any other suitable type of sensor configured to detect the presence and/or absence of a user's ear or head.

A cross-sectional side view of an illustrative earbud with a speaker driver and an associated ear presence sensor is shown in FIG. **8**. As shown in FIG. **8**, earbud **28** may have a housing such as housing **66**. Speaker **40** may be mounted within housing **66** overlapping an acoustic grill formed from structures such as mesh **68** and **70** or other acoustic mesh. During operation, sound **88** may pass through the acoustic mesh. For example, speaker **40** may produce sound that is received by a user's ear or other external object **80**.

When external object **80** is sufficiently close to earbud **28**, the presence of external object **80** may be detected. For example, control circuitry **45** may measure the resistance between mesh electrodes **68** and **70** using conductive paths **82** or may use capacitance measurements in monitoring for the presence of object **80**. The measured resistance (or capacitance) may then be used to determine whether earbud **28** is in the user's ear or is out of the user's ear. Control circuitry **45** may also use sensors such as sensor **44** of FIG. **8** to monitor for the presence or absence of external objects such as the user's ear. As shown in FIG. **8**, sensor **44** may have a transmitter such as transmitter **44**T and may have a receiver such as receiver **44**R. During operation of sensor **44**, sensor **44** may transmit signals such as signal **84** and may gather reflected signals such as signal **86**. The strength of received signal **86** may be used to measure whether or not external object **80** is in the presence of earbud **28**.

Sensor **44** may be a light-based sensor. For example, transmitter **44**T may be a light-emitting diode or laser that emits light **84** (e.g., infrared light, visible light, etc.) and receiver **44**R may be a light detector (e.g., a photodiode or phototransistor) that measures the amount of light **84** that is reflected as reflected light **86** from external object **80**. When the amount of light that is reflected from external object **80** is high, circuitry **45** can conclude that earbud **28** is in the user's ear. When the amount of light that is reflected from external object **80** is low, circuitry **45** can conclude that earbud **28** is out of the user's ear.

If desired, sensor **44** may be a sensor that emits and receives acoustic signals. For example, transmitter **44**T may be an ultrasonic signal transducer that transmits ultrasonic signals **84**. Receiver **44**R may be an ultrasonic signal receiver that measures the amount of corresponding ultrasonic signal **84** that is reflected as reflected signal **86** from external object **80**. When the amount of ultrasonic signal that is reflected from external object **80** is low, circuitry **45** can conclude that earbud **28** is not in the user's ear. When the amount of ultrasonic signal that is reflected from external object **80** is high, circuitry **45** can conclude that earbud **28** is currently in the user's ear.

In configurations where noise cancellation operations are performed locally in accessory **20**, circuitry **45** in accessory **20** may use information from sensor structures **44** to control noise cancellation circuitry **48**. For example, when information from sensor structures **44** indicates that earphones **20** have been removed from a user's ears, control circuitry **45** may automatically deactivate noise cancellation circuitry **48**. When information from sensor structures **44** indicates that earphones **20** have been placed in or on a user's ears, control circuitry **45** may automatically deactivate noise cancellation circuitry **48**, thereby conserving the battery life of earphones **20**.

In configurations where noise cancellation operations are performed remotely in device **10**, circuitry **32** (FIG. **2**) in accessory **20** may receive information from sensor structures **44** via cable **26**. Circuitry **32** may control noise cancellation functions based on the information from sensor structures **44**. For example, when information from sensor structures **44** indicates that earphones **20** have been removed from a user's ears, control circuitry **32** may automatically deactivate noise cancellation circuitry **46**. When information from sensor structures **44** indicates that earphones **20** have been placed in or on a user's ears, control circuitry **32** may automatically activate noise cancellation circuitry **46**, thereby conserving the battery life of device **10**.

A flow chart of illustrative steps involved in using system **8** is shown in FIG. **9**. During the operations of step **100**, earphones **20** may be located in or on the ears of a user and may be operated normally while using sensor circuitry **44** to monitor for the presence or absence of speaker housings **28** of accessory **20** in or on the ears of a user. In configurations where earphones **20** are over-the-ear headphones (FIG. **7**), sensor circuitry **44** may be used to monitor the presence or absence of the user's head near headband **78** or the presence or absence of the user's ears near over-the-ear speaker housings **28**. Circuitry **45** (and/or circuitry **32**, if desired) may be used in evaluating sensor data and taking appropriate action. Configurations in which control circuitry **45** is used in taking action based on sensor data are sometimes described herein as an example.

Examples of operations that may be performed by system **8** during step **92** include audio-based operations such as playing media content (e.g., media content stored on device **10** or media content provided by an online service), providing a user with audio associated with a telephone call, providing audio associated with a video chat session to the user, or otherwise presenting audio content through earphones **20**. Audio may be played in stereo so that left and right earbuds receive corresponding left and right channels of audio, may be played using a multi-channel surround sound scheme, or may be played using a monophonic (mono) sound scheme in which both the left and right channels of audio are identical. During the audio-based operations of step **92**, noise cancellation circuitry **48** (or noise cancellation circuitry **46** in device **10**) may be active to reduce the impact of ambient noise on the audio content played through earphones **20**. Configurations where noise cancellation circuitry **48** in earphones **20** is used to perform noise cancellation operations is sometimes described herein as an example. It should be understood, however, that the steps of FIG. **9** may also be performed in configurations where noise cancellation circuitry (e.g., noise cancellation circuitry **46**) is located in device **10**.

During the monitoring operation of step **100**, circuitry **45** can use user detection sensors **44** to determine whether or not earphones **20** are in or on the user's ears.

If, during the operations of step **100**, it is determined that earphones **20** have been removed from the user's ears, circuitry **45** may take suitable action at step **102**. For example, circuitry **45** may deactivate noise cancellation circuitry **48** in response to information from sensor structures **44** indicating that earphones **20** have been removed from the user's ears. If desired, circuitry **32** in device **10** may adjust the audio content being played based on the information gathered by sensor structures **44**. For example, circuitry **32** may pause or stop the audio content being played, may adjust the playback volume (audio signal drive strength), may switch from a stereo playback scheme to a monophonic playback scheme, or may take other suitable actions based on information from sensor structures **44**.

After taking suitable actions at step **102**, device **10** can be operated in an earphones-off mode (step **104**). For example, earphones **20** may operate with noise cancellation circuitry deactivated (i.e., turned off). This may include continuing to play audio content without performing noise cancellation operations, operating with paused or stopped audio playback, etc.

During the operations of step **104**, ear presence sensor structures **44** may be used to monitor for the presence of earphones **20** in or on the ears of the user.

If, during the operations of step **104**, sensor structures **44** determine that earphones **20** have been placed in or on the user's ears, appropriate action may be taken at step **106**. Suitable actions that may be taken by system **8** in response to earphones **20** being placed in or on the user's ears include activating noise cancellation circuitry **48**, resuming media playback, and/or restoring a previous volume level of the media playback (as examples). Operations may then proceed to step **100**, where system **8** may operate in an earphones-on mode while circuitry **45** monitors sensor structures **44** to determine when earphones **20** are removed from the user's ears.

The foregoing is merely illustrative of the principles of this invention and various modifications can be made by those skilled in the art without departing from the scope and spirit of the invention. The foregoing embodiments may be implemented individually or in any combination.

What is claimed is:

1. Earphones, comprising:

speakers;

noise cancellation circuitry;

ear presence sensor structures, wherein the ear presence sensor structures comprise light-based sensor structures having at least one light source that emits infrared light and at least one light detector that detects the infrared light emitted by the at least one light source;

control circuitry configured to gather information from the ear presence sensor structures indicating whether the speakers are present at the ears of a user and configured to adjust the noise cancellation circuitry in response to the information from the ear presence sensor structures;

housing structures in which the speakers are mounted, wherein at least one light-based sensor structure is mounted in the housing structures; and

a headband that connects the housing structures, wherein at least one light-based sensor structure is mounted in the headband, and wherein the control circuitry adjusts the noise cancellation circuitry in response to the information from the light-based sensor structures in the housing structures and the light-based sensor structures in the headband.

2. The earphones defined in claim **1** further comprising a battery, wherein the control circuitry is configured to adjust the noise cancellation circuitry to reduce power consumption of the battery.

3. A method for operating a pair of earphones having noise cancellation circuitry and configured to play audio content for a user comprising:

with control circuitry in the earphones, gathering information from ear presence sensor structures in the earphones on whether the earphones are present at the ears of the user; and

in response to the information from the ear presence sensor structures, adjusting the noise cancellation circuitry in the earphones, wherein the ear presence sensor structures comprise an accelerometer-based sensor that detects changes in acceleration, wherein gathering information from the ear presence sensor structures comprises gathering earphone movement information from the accelerometer-based sensor, and wherein adjusting the noise cancellation circuitry comprises deactivating the noise cancellation circuitry in response to the earphone movement information indicating that the earphones are in motion.

4. The method defined in claim **3** wherein the information indicates that the earphones are not present at the ears of the user based on the detected motion of the earphones and wherein adjusting the noise cancellation circuitry comprises deactivating the noise cancellation circuitry in response to determining that the earphones are not present at the ears of the user.

5. The method defined in claim **4** wherein the audio content is played through a pair of speakers, the method further comprising:

adjusting the audio content that is played through the speakers in response to determining that the earphones are not in the ears of the user.

6. The method defined in claim **5** wherein adjusting the audio content that is played through the speakers comprises pausing the audio content that is played through the pair of speakers.

7. The method defined in claim **3** wherein the information indicates that the earphones are present at the ears of the user and wherein adjusting the noise cancellation circuitry comprises activating the noise cancellation circuitry in response to determining that the earphones are present at the ears of the user.

8. An electronic device operable to receive information from ear presence sensor structures in earphones coupled to the electronic device, comprising:

noise cancellation circuitry; and

control circuitry configured to gather information from the ear presence sensor structures indicating whether speakers in the earphones are present at the ears of a user and configured to adjust the noise cancellation circuitry in response to the information from the ear presence sensor structures, wherein adjusting the noise cancellation circuitry comprises deactivating the noise cancellation circuitry while continuing to play audio content through the speakers.

9. The electronic device defined in claim **8** wherein the ear presence sensor structures comprise an accelerometer-based sensor and wherein the control circuitry is configured to gather earphone movement information from the accelerometer-based sensor.

10. The electronic device defined in claim **8** further comprising a battery, wherein the control circuitry is configured to adjust the noise cancellation circuitry to reduce power consumption of the battery.

11. The electronic device defined in claim **8** wherein the control circuitry is configured to adjust audio playback to the earphones based on the information from the ear presence sensor structures.

12. The electronic device defined in claim **8** wherein the control circuitry is configured to pause audio playback to the earphones based on information from the ear presence sensor structures indicating that the speakers in the earphones are not present at the ears of the user.

13. A method for operating an electronic device having noise cancellation circuitry and configured to play audio content for a user through a pair of earphones, comprising:

with control circuitry in the electronic device, gathering information from ear presence sensor structures in the earphones on whether the earphones are present at the ears of the user of the electronic device; and

in response to the information from the ear presence sensor structures, adjusting the noise cancellation circuitry in the electronic device, wherein the ear presence sensor structures comprise an accelerometer-based sensor that detects changes in acceleration, wherein gathering information from the ear presence sensor structures comprises gathering earphone movement information from the accelerometer-based sensor, and wherein adjusting the noise cancellation circuitry comprises deactivating the noise cancellation circuitry in response to the earphone movement information indicating that the earphones are in motion.

14. The method defined in claim **13** wherein the information indicates that the earphones are not present at the ears of the user based on the detected motion of the earphones and wherein adjusting the noise cancellation circuitry comprises deactivating the noise cancellation circuitry in response to determining that the earphones are not present at the ears of the user.

15. The method defined in claim **14** further comprising: adjusting the audio content that is played through the earphones in response to determining that the earphones are not present at the ears of the user.

16. The method defined in claim **15** wherein adjusting the audio content that is played through the earphones comprises pausing the audio content that is played through earphones.

17. The method defined in claim **13** wherein the information indicates that the earphones are present at the ears of the user and wherein adjusting the noise cancellation circuitry comprises activating the noise cancellation circuitry in response to determining that the earphones are present at the ears of the user.

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